CE&P, LLC. GREET Pathway for the Production of Ethanol from Sugarcane and Sweet Sorghum

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Summary

California Ethanol and Power, LLC (CE&P) is building a biorefinery that converts sugarcane and sweet sorghum to ethanol and bio CNG. Electric power is a co-product. The carbon intensity (CI) under the California Low Carbon Fuel Standard (LCFS) for CE&P's sugarcane ethanol pathway are 54.47 g CO_2e/MJ for ethanol produced from sugarcane and 39.00 g CO_2e/MJ for ethanol produced from sweet sorghum. Table 1 outlines the documents submitted in support of this pathway application.

Table 1. Method 2A/2B application supporting documentation and file list

	Document	Confidentiality	Comments
X	1. Completed Method 2A2B application form.		
X	2. Pathway document	Includes confidential business information	
	3. Utility invoices		Plant has not been built yet.
	4. Fuel production records		Plant has not been built yet.
	5. Trucking/transport invoices		Plant has not been built yet.
X	6a. CA-GREET1.8b spreadsheet and results	Includes confidential business information	
X	6b. Spreadsheets, data files, and similar files documenting the calculations behind the fuel life cycle analysis.	Includes confidential business information	
X	7. List of all stationary combustion equipment associated with the production facility.	Includes confidential business information	
X	8a. Process flow diagrams covering the complete production process, including all inputs (feedstocks, process energy, etc.) and outputs (finished fuel, co-products, wastes, etc.)	Includes confidential business information	
X	8b. Production process schematics, technical drawings flow diagrams, maps, or other graphical representations (other than/in addition to the required process flow diagram).	Includes confidential business information	Included in the independent engineering report.
X	9. All operating permits issued by the local air pollution control authority	Includes confidential business information	EIR issued by Imperial County
	10. RFS2 Third party engineering report		Plant has not been built yet.
X	11. Letter of Attestation		

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Pathway Summary

A Well-To-Tank (WTT) fuel cycle analysis of the California Ethanol and Power (CE&P) sugarcane to ethanol pathway includes all steps from sugarcane farming in the Imperial Valley to ethanol transported for use. Tank-to-wheel (TTW) analysis includes fuel combustion in a vehicle. Together, WTT and TTW analysis are combined to provide a total well-to-wheel (WTW) analysis that determined the fuel cycle greenhouse gas emissions, termed carbon intensity (CI), associated with CE&P sugarcane ethanol.

A Life Cycle Analysis Model called the **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET) developed by Argonne National Laboratory has been used to calculate the energy use and greenhouse gas (GHG) emissions generated during the entire process starting from farming sugarcane to producing and combusting ethanol in an internal combustion engine. Life Cycle Associates, with assistance from ARB modified the original GREET model to create a California specific model termed the CA_GREET model. Changes were restricted mostly to input factors (emission factors, generation mix, transportation distances, etc.) with no substantial changes in methodology inherent in the original GREET model. This California modified GREET model (v1.8b, released December 2009) forms the basis of the analysis summarized in this document. A disaggregated model of CA_GREET has been developed by Life Cycle Associates and has been used to calculate the energy use and Greenhouse Gas (GHG) emissions associated with a WTW analysis for sugarcane ethanol produced in the Imperial Valley for use in light duty vehicles in California.

The CE&P fuel plant, located in Brawley California, produces ethanol, biogas, and electricity from combustion of bagasse. This document details the energy and inputs required to produce sugarcane ethanol from sugarcane grown in California's Imperial Valley and transported to California blending terminals for blending with CARBOB.

The fuel pathways include sugarcane/sweet sorghum farming, sugarcane/sweet sorghum transport, ethanol production, co-product production, ethanol transport and distribution and fuel combustion. The source of energy for the facility is electricity produced from sugarcane bagasse. The pathways examined here is:

- Imperial Valley sugarcane ethanol production, with biogas co-production and electricity production credit
- Imperial Valley sweet sorghum ethanol production, with biogas co-production and electricity production credit

The framework for the pathway is provided by the CA_GREET Brazilian sugarcane to ethanol pathway. The system boundary diagram in Figure 1 shows the components that form the sugarcane or sorghum ethanol pathways. The feedstock phase includes farming, fertilizer inputs, and sugarcane transport. Indirect land use change (ILUC) impacts associated with the agricultural activity of growing sugarcane are taken from the ARB's GTAP analysis of Brazilian sugarcane ethanol. ILUC impacts associated with the agricultural activity of growing sweet sorghum are taken from the ARB's GTAP analysis of corn ethanol.

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The biorefinery produces ethanol, renewable gas for CNG, and electric power. Farming inputs, plant emissions, and co-product power are allocated to ethanol and CNG based on the lower heating value of the fuels. Both ethanol and CNG will generate RINs under the RFS2 program. This document summarizes the input parameters necessary to represent CE&P's fuel pathway and the life cycle energy and greenhouse gas emission results calculated by the CA_GREET1.8b model.

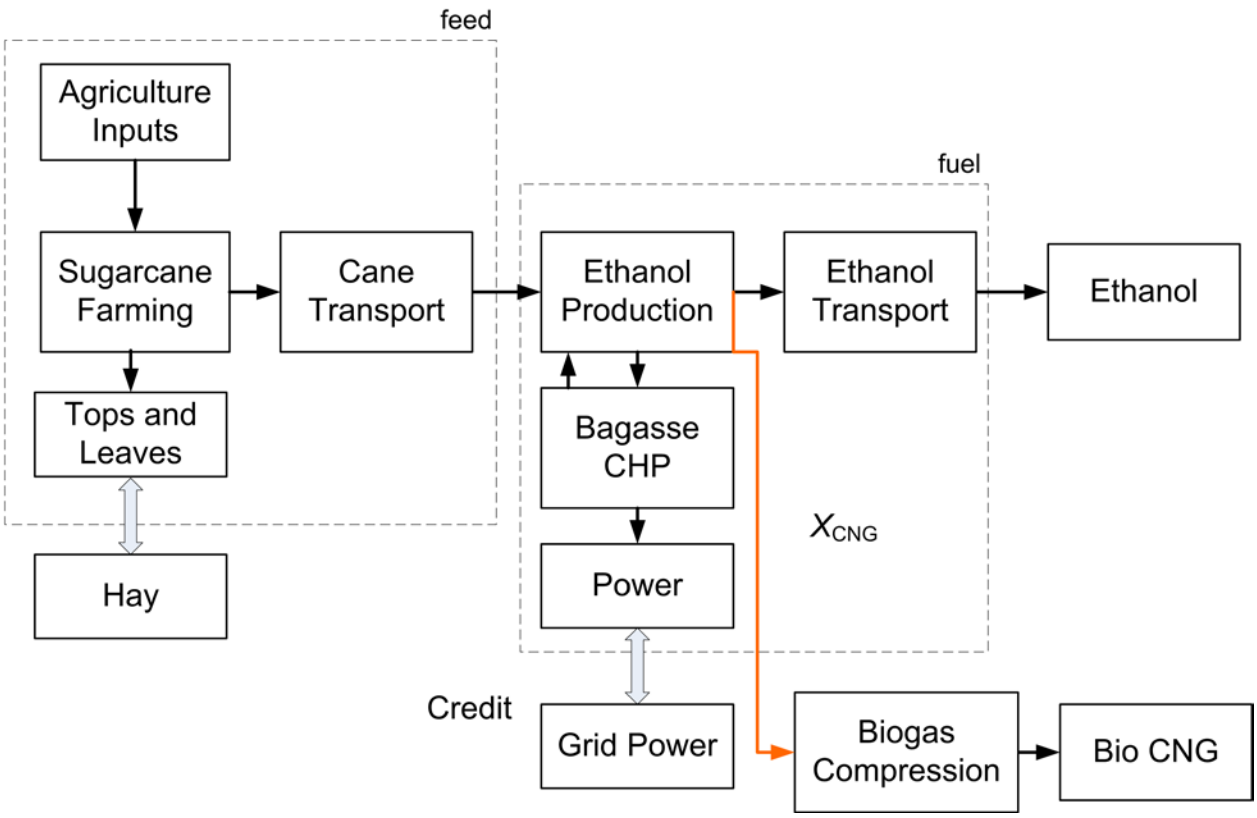

Figure 1. System Boundary Diagram for Sugarcane/Sweet Sorghum Ethanol

Result Summary

The well-to-tank (WTT) results for CE&P ethanol from sugarcane and sweet sorghum respectively are 7.67 g CO_2e/MJ and 8.20 g CO_2e/MJ for ethanol produced with bagasse based power and natural gas on an anhydrous basis. These results do not include vehicle methane or N_2O emissions, denaturant, or indirect land use conversion (ILUC). The well-to-wheel (WTW) emissions are defined as WTT emission plus fossil carbon in fuel and land use change impacts, and are presented in Table 2. The direct carbon intensity of each pathway includes the WTT emissions presented in Table 1, plus ARB's adder for denaturant of 0.8 g/MJ and the adder for land use change of 46 g CO_2e/MJ for sugarcane and 30 g CO_2e/MJ for sweet sorghum. Table 1 summarizes the total carbon intensity and baseline values from the LCFS look-up table for comparison. The full life cycle WTW results for CE&P ethanol from sugarcane and sweet sorghum respectively are 54.47 g CO_2e/MJ and 39.00 g CO_2e/MJ respectively.

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Table 1. Total Carbon Intensity for CE&P Ethanol from Sugarcane and Sweet Sorghum Compared to Baseline Brazilian Sugarcane Ethanol (g CO_2e/MJ)

Pathway	Direct CI	Denaturant Adder[a]	Indirect LUC	Total	% Baseline reduction
ARB Pathway ETHS002; Brazilian sugarcane with average production process, mechanized harvesting and electricity co-product credit[b]	12.40	N/A	46	58.40	N/A
CE&P Imperial Valley Sugarcane to ethanol, with mechanized harvesting and electricity co-product credit[c]	7.67	0.8	46	54.47	7%
CE&P Imperial Valley Sweet Sorghum to ethanol, with mechanized harvesting and electricity co-product credit[d]	8.20	0.8	30	39.00	N/A

[a] Table C of the Sugarcane Ethanol Pathway document states that the effect of % denaturant between anhydrous and denatured ethanol results in a 0.8 g CO_2e/MJ addition. This value is uniformly applied across all pathways, which is the same method applied by ARB.
[b] http://www.arb.ca.gov/fuels/lcfs/lu_tables_11282012.pdf
[c] Assumes same ILUC as Brazilian sugarcane ethanol.
[d] Assumes same ILUC as corn ethanol.

CE&P Sugarcane Ethanol Fuel Pathway

Ethanol Production

Sugarcane ethanol production requires process heat and electricity inputs for feedstock preparation, fermentation, distillation and dehydration. The CE&P plant produces ethanol, biogas, and excess electricity from bagasse combustion. GREET inputs were calculated from CE&P process data for the facility design.

The life cycle emissions from natural gas production are calculated using CA_GREET. The calculations are performed using the California region in CA_GREET. The fuel plant life cycle analysis was separated into the two pathways described here. The main pathway for CE&P ethanol production is the production of ethanol from sugarcane and sweet sorghum using bagasse combustion electric power and natural gas. Biogas is co-produced with the ethanol, and is examined in a separate pathway document. The analysis is based on facility material balance information.

Allocation to Products

Inputs and outputs are allocated between the two fuel products: ethanol and bio CNG on an energy basis. All inputs in the pathway are multiplied by the [redacted]% ethanol allocation factor. GREET inputs for sugarcane and sweet sorghum feedstock are expressed as a yield (rather than input per gallon); so, these values are divided by [redacted]%.

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For example, the ethanol to sugarcane yield of [redacted] gallons per wet tonne is adjusted by the allocation factor to generate a yield of [redacted] gallons of ethanol equivalent per wet tonne sugarcane which represents a sugarcane input of [redacted] kg/gal = [redacted].

Table 2. Co-product Allocation Factors

Input/Output	Sugarcane	Sorghum
Feedstock (wet tonnes/year)	[redacted]	[redacted]
Products (mmBtu)	[redacted]	[redacted]
Ethanol	[redacted]	[redacted]
Biogas	[redacted]	[redacted]
Total	[redacted]	[redacted]
Ethanol (%)	[redacted]	[redacted]
Biogas (%)	[redacted]	[redacted]

Farming and Transport

Sugarcane farming requires fuel, electricity and agricultural chemicals (fertilizers, pesticides). The CE&P sugarcane results presented here are based on the inputs assumed by ARB for the established sugarcane ethanol fuel pathways under the LCFS. Therefore, the results in Btu/ton and g/MJ are documented in ARB sugarcane ethanol pathway. The calculations are performed using the U.S. Average region in CA_GREET, data inputs, assumptions and calculations tables are detailed in Attachment A: Data Sources.

CA_GREET 2.0 default inputs for sugarcane farming are assumed for fertilizers, herbicides, and pesticides in the farming of CE&P sugarcane and sweet sorghum.

The default pathway for modeling Brazilian sugarcane farming in GREET is configured for a mix of mechanical and manual harvesting where the manually harvested cane tops and leaves are burned in the fields. However, in the case of CE&P's sugarcane farming practices, no field burning occurs and the sugarcane is harvested mechanically. Therefore, there are no emissions associated with burning the sugarcane.

About [redacted] of the wet sugarcane is tops and leaves. [redacted] of the tops and leaves remain attached to the stalk during harvesting. This component is combusted along with the bagasse to produce electricity.

CE&P plans on collecting the remaining tops and leaves and baling these for animal feed or other purposes. About [redacted]% of the tops and leaves will remain in the field. A co-product credit for this material is not included in the pathway.

Table 3 displays the key inputs for CE&P farming and transport of sugarcane and sweet sorghum in the Imperial Valley.

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Table 3. Key Parameter Inputs for CE&P Farming and Transport

CA_GREET Inputs	Units	Sugarcane	Sweet Sorghum
Farming energy consumption	Btu/wet tonne	[redacted]	[redacted]
N input[1]	(g/wet tonne)	[redacted]	[redacted]
Ammonia[1]	%	[redacted]	[redacted]
Urea[1]	%	[redacted]	[redacted]
Ammonium Nitrate[1]	%	[redacted]	[redacted]
P_2O_5 fertilizer[1]	(g/wet tonne)	[redacted]	[redacted]
K_2O fertilizer[1]	(g/wet tonne)	[redacted]	[redacted]
$CaCO_3$ fertilizer[1]	(g/wet tonne)	[redacted]	[redacted]
Herbicide[1]	(g/wet tonne)	[redacted]	[redacted]
Pesticide[1]	(g/wet tonne)	[redacted]	[redacted]
Diesel truck from field to plant	(miles)	[redacted]	[redacted]

1. Assumes CA_GREET2.0 default values.

Ethanol production

Sugarcane ethanol production requires process heat and electricity inputs for feedstock preparation, fermentation, distillation and dehydration. The input parameters for CE&P ethanol produced with sugarcane are presented below in Table 4. The natural gas input includes natural gas for process heat. Electric power input includes power to operate blowers, pumps, and other equipment.

Table 4. Key Parameter Inputs for CE&P Ethanol Production

CA_GREET Inputs	Units	Sugarcane	Sweet Sorghum
Plant Energy	(Btu/gal)	[redacted]	[redacted]
Fuel Shares (Fossil)			
Natural Gas (Btu/gal)	% of total	[redacted]	[redacted]
Residual oil (Btu/gal)	% of total	[redacted]	[redacted]
Bagasse	(tonne/gal)	[redacted]	[redacted]
Exported Electricity	(kWh/gal)	[redacted]	[redacted]
Ethanol + BioCNG Yield	(gal/wet tonne feed)	[redacted]	[redacted]

The production and transport of the co-produced bioCNG results in a small amount of leakage. The ARB default of 1% methane leakage, provided in the LCFS readoption framework and GREET 2.0, is assumed here. Given a co-production rate of [redacted] standard cubic feet of biomethane per gallon of ethanol, this results in a release of [redacted] g CO_2e/MJ of ethanol. This number is included in the direct emissions of ethanol production from well to tank.

Figure 2 shows the site location of the CE&P facility in Brawley, CA and the adjoining gas and electricity lines. Figure 3 shows the site in the context of the greater Imperial Valley Area.

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Figure 2. Aerial Photo of CE&P Facility Site in Brawley, CA

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Figure 3. Brawley Area Map of CE&P Facility Site

Exported Electricity Credit

The life cycle carbon intensity of CE&P ethanol also receives several displaced primary production credits. For one, the CE&P facility burns bagasse from the sugarcane feedstock to produce steam and electricity. This electricity is used in the plant and the excess is exported to the grid. The total electricity produced is over [redacted] GWh per year. After subtracting the electricity used to run the facility, the net exported electricity is [redacted] GWh per year, or [redacted] kWh per gallon of ethanol and bioCNG produced.

Ethanol Transport and Distribution

Inputs

Ethanol produced at the Brawley, California plant is transported by truck to the Colton terminal, in California. Truck distribution is assumed via the CA_GREET default. Transport by truck includes a return trip to return the truck to the origin, whereas transport by rail is one-way. The analysis assumes diesel fuel for all transport segments. The input parameters describing these transport modes, mode shares and distances are presented in Table 7. The rail mileage is an input to the CA_GREET model as outlined in the Modifications to CA_GREET section of this document.

Table 5. Input Parameters for Ethanol Transport and Distribution

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Mode	Distance (mi)	Mode Share
Heavy Duty Truck	155	100%
Truck to Retail	50	100%

Ethanol Transport

The finished ethanol is transported by truck from the CE&P facility in Brawley, California to the rail terminal in Colton, California is 155 miles. Distances were obtained using Google Maps (http://www.mapquest.com/) as per Figure 4.

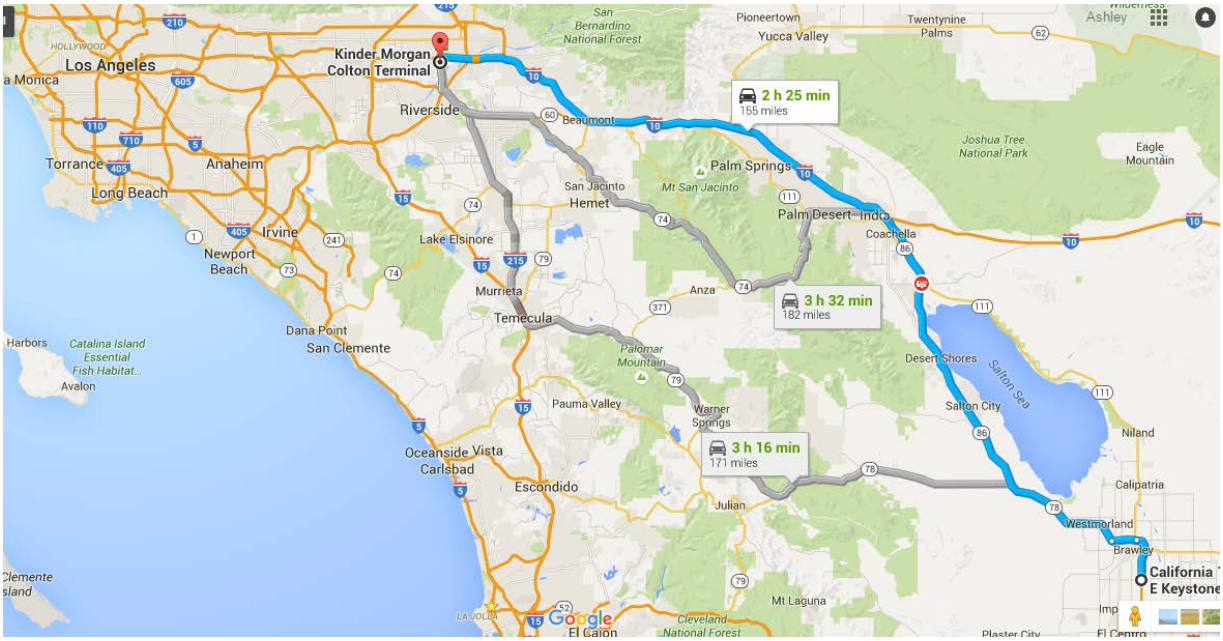

Figure 4. Transport distance from Brawley, CA to Colton, CA

Transport and Distribution emissions are calculated using the CA_GREET model. The truck transport to terminal distance is entered into GREET cell T&D_Flowcharts!R1427 and the emissions data obtained from the etoh worksheet, as per Table 8. The region is set to California Marginal as specified in the Regional LT.

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Table 6. GREET Ethanol Transport and Distribution

Emissions	CE&P T&D
Energy Inputs (Btu/mmBtu)	
Total energy	[redacted]
Fossil fuels	[redacted]
Coal	[redacted]
Natural gas	[redacted]
Petroleum	[redacted]
Emissions (g/mmBtu)	
VOC	[redacted]
CO	[redacted]
CH_4	[redacted]
N_2O	[redacted]
CO_2 including VOC & CO	[redacted]

Life Cycle Results

The life cycle energy and greenhouse gas emission results for CE&P ethanol production are shown below. The calculations were performed in a replicate of "EtOH" tab of the CA_GREET 1.8b model. The complete data set for feedstock, co-product credits, ethanol production, transport and distribution as well as the total WTW emissions are presented in Table 5 and 6. The GREET inputs for each step in the life cycle are included in the Modification to the CA_GREET model section of this document.

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Table 7. Energy and Greenhouse Gas Results for CE&P Imperial Valley Sugarcane to Ethanol Production with Bagasse Electricity Export (Btu/mmBtu and g/mmBtu)

Results are specified as BTU or grams per MMBTU of Ethanol	**Sugarcane Ethanol with Exported Electricity and Natural Gas Boiler**			**CA_GREET Total WTT (well to tank) results**
	Sugarcane w/o loss factor	**Sugarcane w/ loss factor**	**Ethanol**	
Loss factor	[redacted]	[redacted]	[redacted]	[redacted]
Energy Inputs (Btu/mmBtu)				
Total energy	[redacted]	[redacted]	[redacted]	[redacted]
Fossil fuels	[redacted]	[redacted]	[redacted]	[redacted]
Coal	[redacted]	[redacted]	[redacted]	[redacted]
Natural gas	[redacted]	[redacted]	[redacted]	[redacted]
Petroleum	[redacted]	[redacted]	[redacted]	[redacted]
Emissions (g/mmBtu)				
VOC	[redacted]	[redacted]	[redacted]	[redacted]
CO	[redacted]	[redacted]	[redacted]	[redacted]
CH_4	[redacted]	[redacted]	[redacted]	[redacted]
N_2O	[redacted]	[redacted]	[redacted]	[redacted]
CO_2	[redacted]	[redacted]	[redacted]	[redacted]
Total GHG (g CO_2e/mmBtu)				[redacted]
(g CO_2e/MJ)				[redacted]
Biomethane Leakage (1%)				[redacted]
Land Use Change				46
Denaturant (CARBOB blended at 0.77% with anhydrous EtOH)				0.8
Total Carbon Intensity			**(g CO_2e/MJ EtOH)**	**54.47**
ARB Pathway ETHS002; Brazilian sugarcane w/ electricity export				58.4

*Table C of the Sugarcane Ethanol Pathway document states that the effect of % denaturant between anhydrous and denatured ethanol results in a 0.8 g CO_2e/MJ addition. This value is uniformly applied across all pathways.

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Table 8. Energy and Greenhouse Gas Results for CE&P Sweet Sorghum Ethanol Production with Bagasse Electricity Export (Btu/mmBtu and g/mmBtu)

Results are specified as Btu or grams per MMBtu of Ethanol	**Sweet Sorghum Ethanol with Exported Electricity and Natural Gas Boiler**			**CA_GREET Total WTT (well to tank) results**
	Sweet Sorghum w/o loss factor	**Sweet Sorghum w/ loss factor**	**Ethanol**	
Loss factor	[redacted]	[redacted]	[redacted]	[redacted]
Energy Inputs (Btu/mmBtu)				
Total energy	[redacted]	[redacted]	[redacted]	[redacted]
Fossil fuels	[redacted]	[redacted]	[redacted]	[redacted]
Coal	[redacted]	[redacted]	[redacted]	[redacted]
Natural gas	[redacted]	[redacted]	[redacted]	[redacted]
Petroleum	[redacted]	[redacted]	[redacted]	[redacted]
Emissions (g/mmBtu)				
VOC	[redacted]	[redacted]	[redacted]	[redacted]
CO	[redacted]	[redacted]	[redacted]	[redacted]
CH_4	[redacted]	[redacted]	[redacted]	[redacted]
N_2O	[redacted]	[redacted]	[redacted]	[redacted]
CO_2	[redacted]	[redacted]	[redacted]	[redacted]
Total GHG (g CO_2e/mmBtu)				[redacted]
(g CO_2e/MJ)				[redacted]
Biomethane Leakage (1%)				[redacted]
Land Use Change				30
Denaturant (CARBOB blended at 0.77% with anhydrous EtOH)				0.8
Total Carbon Intensity			**(g CO_2e/MJ EtOH)**	**39.00**
ARB Reference Pathway				N/A

*Table C of the Sugarcane Ethanol Pathway document states that the effect of % denaturant between anhydrous and denatured ethanol results in a 0.8 g CO_2e/MJ addition. This value is uniformly applied across all pathways.

Modifications to the CA_GREET Model

CE&P has conducted its analysis of direct effects on carbon intensity for this pathway using (CA_GREET, v.1.8b (Dec. 2009) (See http://www.arb.ca.gov/fuels/lcfs/ca_greetl.8b_dec09.xls)). The standard inputs and parameters specified in CA_GREET remain unchanged except as noted in Table 9 as shown below.

Both the Sugarcane and Ethanol production Phases are calculated by selecting California Marginal in the regional LT tab.

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Table 9. Changes to Input Parameters of GREET 1.8b CE&P Model

Parameters	CA_GREETv1.8b	CA_GREETv1.8b	CE& P CA_GREETv1.8b	CE& P CA_GREETv1.8b
	Worksheet Location	**Default Cell Value**	**Sugarcane Etoh Pathway Values**	**Sweet Sorghum Etoh Pathway Values**
Biomass Feedstock				
Farming Collection Energy	Fuel_Prod_TS!CR259:CR265	41,592 Btu/dry tonne	[redacted]	[redacted]
N Fertilizer Use	Inputs!H191	1091.7 g/tonne		
N Fertilizer Mix				
- N Fertilizer mix: Ammonia (NH3)	Ag_Inputs!H65	70.7%	[redacted]	[redacted]
- N Fertilizer mix: Urea (NH2CONH2)	Ag_Inputs!I65	21.1%	[redacted]	[redacted]
P2O5 Fertilizer Use	Inputs!H192	120.8 g/tonne	[redacted]	[redacted]
K2O Fertilizer Use	Inputs!H193	193.6 g/tonne	[redacted]	[redacted]
CaCO3 Fertilizer Use	Inputs!H194	5337.7 g/tonne	[redacted]	[redacted]
Herbicide Use	Inputs!H196	26.90 g/tonne	[redacted]	[redacted]
Insecticide Use	Inputs!H1917	2.21 g/tonne	[redacted]	[redacted]
Ethanol Production				
Yield	Fuel_Prod_TS!CR273:CR279	24.04 gal/wet tonne	[redacted]	[redacted]
Total Energy	Fuel_Prod_TS!CN273:CN279	251 btu/gal	[redacted]	[redacted]
Energy Shares				
Residual Oil	Etoh!CJ148	100%	[redacted]	[redacted]
Natural Gas	Etoh!CJ151	0%	[redacted]	[redacted]
Net Electricity Export	Inputs!D307	0.00 kWh/gal	[redacted]	[redacted]
Ethanol Transport				
Truck transport of ethanol to blending terminal	T&D_Flowcharts!R1427	100 miles	155 miles	155 miles
Truck transport of sugarcane to facility	T&D_Flowcharts!F1377	12 miles	33 miles	30 miles

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